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RESEARCH MEMORANDUM

EXPERIMENTAL AND CALCULATED HINGE MOMENTS OF TWO AILERONS
ON A 42.7° SWEPTBACK WING AT A MACH NUMBER OF 1.9

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EXPERIMENTAL AND CALCULATED HINGE MOMENTS OF TWO AILERONS

ON A 42.7° SWEEPBACK WING AT A MACH NUMBER OF 1.9

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SUMMARY

A 42.7° sweptback wing was tested with basic and blunt ailerons in the Langley 9- by 12-inch supersonic blowdown tunnel at a Mach number of 1.9 and a Reynolds number of 2.2×10^6 . The wing had an aspect ratio of 4, a taper ratio of 0.5, and an 8-percent-thick symmetrical biconvex airfoil section in the free-stream direction. The interchangeable 20-percent-chord ailerons were located outboard. The profile of the basic aileron was made to conform to the contour of the wing, and the profile of the blunt aileron had flat sides and a trailing-edge thickness of one-half the hinge-line thickness.

The rolling-moment coefficients of both ailerons varied approximately linearly with aileron deflection, and the blunt aileron was about 10 percent more effective than the basic aileron. Hinge moments varied approximately linearly with angle of attack and with aileron deflection for both ailerons and were about 40 percent higher for the blunt aileron than for the basic aileron. Theoretically calculated hinge moments were in good agreement with experimental results. There was no measurable difference in the drag of the two wing-aileron combinations.

INTRODUCTION

A general transonic and supersonic investigation has been conducted in several facilities of the Langley Aeronautical Laboratory of the lateral control characteristics of a 42.7° sweptback wing of aspect ratio of 4 and taper ratio of 0.5, with 8-percent-thick biconvex airfoil sections in a streamwise direction. Free-flight tests (reference 1) and wind-tunnel tests on a transonic bump (reference 2) indicated a reversal in aileron effectiveness in a region of the transonic speed range for a conventional 20-percent-chord aileron with the basic wing profile. Tests of the same configuration at a Mach number of 1.9 in the Langley 9- by 12-inch supersonic blowdown tunnel (reference 3) verified the free-flight results which showed no reversal in the higher Mach number range. In an investigation instigated to improve the aileron effectiveness, it was



found that certain aileron section profiles would eliminate the reversal in effectiveness (references 2 and 4). One of the more promising profiles tested had a blunt trailing edge with thickness equal to one-half the airfoil thickness at the aileron hinge line and had flat surfaces (references 4 and 5). In order to investigate the characteristics of this blunt aileron at a Mach number of 1.9, a wing fitted with such an aileron was tested in the Langley 9- by 12-inch supersonic blowdown tunnel. Reported herein are the results of this investigation which include aileron hinge-moment and rolling-moment characteristics. For the purpose of comparison, the characteristics of the basic aileron with biconvex sections are included. The wing was tested in the presence of a fuselage at a Reynolds number of 2.2×10^6 .

SYMBOLS

C_L	lift coefficient $\left(\frac{\text{Lift}}{qS} \right)$
C_D	drag coefficient $\left(\frac{\text{Drag}}{qS} \right)$
C_m	pitching-moment coefficient $\left(\frac{\text{Pitching moment about } 0.25\bar{c}}{qS\bar{c}} \right)$
C_l	rolling-moment coefficient $\left(\frac{\text{Rolling moment}}{2qSb} \right)$
C_h	hinge-moment coefficient $\left(\frac{\text{Hinge moment about hinge axis}}{2q (\text{Moment of area about hinge axis})} \right)$
S	entire area of semispan wing including part covered by fuselage (17.943 sq in.)
\bar{c}	mean aerodynamic chord of entire wing area (3.101 in.)
b	twice the distance from the wing root chord to the tip (12.000 in.)
q	free-stream dynamic pressure
α	angle of attack relative to free-stream direction
δ_{a_L}	deflection of left-wing aileron in plane perpendicular to hinge line, positive when trailing edge is deflected downward

M Mach number
R Reynolds number, based on \bar{c}

MODEL AND TESTS

The semispan wing and half-fuselage are shown in figure 1, and their principal dimensions are given in figure 2. The wing is the same as that described in reference 3 and has an aspect ratio of 4 and a taper ratio of 0.5. The airfoil profile very closely approximates a circular-arc section in a plane normal to the quarter-chord line. The airfoil section parallel to the air stream is approximately 8 percent thick, and its ordinates are given in table I. The steel wing and brass fuselage have polished surfaces. In mounting the wing and fuselage in the tunnel, the root end of the wing was displaced from the axis of the fuselage in order to make the exposed wing area approximately the same as in references 2 and 4. The root end of the wing serves as the reference axis for the rolling moments. Two wing models, identical, (within construction tolerances) were used in the tests: one, for obtaining hinge-moment measurements and the other, for obtaining the aerodynamic characteristics of the complete wing. This was done because the aileron installation used in measuring hinge moments was neither as smooth nor as rigid as the other aileron installation. It is believed that no large differences were present between the two wings during these tests.

The two ailerons tested are shown in figure 2. The contours of the basic aileron follow the basic contours of the wing. The blunt aileron has flat sides and a trailing-edge thickness of one-half the hinge-line thickness in the free-stream direction.

Each wing was tested with the aileron deflected in one direction at angles of approximately 0° , 4° , 9° , and 13° , measured in a plane normal to the aileron hinge line. By testing the models having symmetrical airfoil sections through a positive and negative angle-of-attack range, data were obtained which would apply to the left panel of a complete wing with both negative and positive aileron deflections.

TUNNEL AND TEST TECHNIQUE

The Langley 9- by 12-inch supersonic blowdown tunnel in which the present tests were made is a nonreturn-type tunnel utilizing the exhaust air of the Langley 19-foot pressure tunnel. Free-stream Mach number is 1.90. The air enters at an absolute pressure of about $2\frac{1}{3}$ atmospheres

and contains about 0.003 pound of water per pound of air. This high moisture content causes condensation to take place in the tunnel, but any effects of the condensation on the tunnel calibration and test results are probably approximately constant inasmuch as the moisture content remains approximately constant.

The dynamic pressure and test Reynolds number decreased about 5 percent during the course of each run because of decreasing pressure of the inlet air. The average dynamic pressure for these tests was 11.7 pounds per square inch, and the average test Reynolds number was 2.2×10^6 .

The semispan wing model was mounted in the presence of a half-fuselage and was cantilevered from the tunnel floor. It was attached to a four-component strain-gage balance which rotated through the angle-of-attack range with the model and measured chord force, normal force, pitching moment, and rolling moment due to normal force.

During these tests the half-fuselage was attached to a tunnel plate, which also rotated with the model, but which was not attached to the balance. The fuselage was shimmed up 0.25 inch from the tunnel wall so that the wing root would be operating in a fuselage boundary layer approximating the free-stream fuselage boundary layer (reference 6). A gap was maintained between the half-fuselage and wing so that forces on the fuselage were not measured.

The ailerons were mounted on an electrical strain-gage beam that measured hinge moments. The installation of the strain-gage beam is shown in figure 3. For the hinge-moment tests, the effective hinge line passed through the electrical centers of the strain gages and the area moment of the aileron about the electrical center was used in computing hinge-moment coefficients. The hinge line for the hinge-moment tests was therefore slightly displaced from that shown in figure 2 for the rolling-moment tests, but the effects of this displacement on the test results are believed to be small. A separate beam, incorporating the aileron deflection, was used for each of the four deflections. The installation simulated a sealed unbalanced aileron.

PRECISION OF DATA

Free-stream Mach number has been calibrated at 1.90 ± 0.02 . This Mach number was used in determining the dynamic pressure. The variation of the static pressure with the tunnel clear was about ± 1.5 percent in the region of the test section normally occupied by the model.

The accuracy of measurements for low aileron deflections is believed to be of the order indicated in the following table:

Variable	Error
α	$\pm 0.05^\circ$
δ_{a_L}	$.25^\circ$
C_L	.005
C_l	.0003
C_m	.001
C_D	.001
C_h	.005

For high aileron deflections the errors in C_l are somewhat higher than that indicated in the table.

RESULTS AND DISCUSSION

The hinge-moment data presented in figures 4 and 5 are from tests of one wing, and the remaining data in figures 5 and 6 are from tests of the other wing. The reason for this was that rolling-moment data from tests of the hinge-moment model were somewhat erratic although no measurable difference between the lift, drag, and pitching-moment of the two models was present.

Angles of aileron deflection were corrected for the strain-gage beam deflections resulting from hinge moments encountered at zero angle of attack during the hinge-moment tests. Further deflections due to changes in hinge moment with angle of attack were insignificant and were not considered. The maximum correction was of the order of 0.2° .

The rolling-moment data presented in figure 4 were obtained by fairing linear, parallel curves of the moment coefficients, measured about the root end of the semispan wing, plotted against angle of attack for different aileron deflections and picking off incremental rolling-moment coefficients due to each aileron deflection. The rigidity of the aileron installation during these tests was such as to require no correction to aileron deflections because of aerodynamic loading.

The values of angle of attack have been corrected for deflections of the balance due to pitching moments. The data of figure 6 have had an additional -0.15° correction applied to the angle of attack to account for stream deflection and possible model dissymmetry. A similar correction was not applied to data obtained during hinge-moment tests because it was impossible to separate the effects of stream angle and model dissymmetry from the effects of small aileron deflections which were present. The only effects of such a correction, however, would be to shift the curves of C_h plotted against α and C_h plotted against δ without changing their slopes.

Hinge-moment characteristics.— Presented in figure 4 are the aileron hinge-moment coefficients as a function of angle of attack for various aileron deflections. The curves are essentially linear and parallel. The hinge-moment coefficients as a function of aileron deflection are presented in figure 5. The slopes of these curves are summarized in table II together with theoretical values calculated as described in the appendix. In each case the magnitudes of the slopes for the blunt aileron were greater than those for the basic aileron. The experimental values of $\partial C_h / \partial \alpha$ and $\partial C_h / \partial \delta$ were -0.014 for the blunt aileron and -0.010 for the basic aileron. The calculated values were in good agreement with the experimental values. Considering the assumptions used in the calculations, this agreement may have been somewhat fortuitous but the trends indicated by theory were substantiated by experiment.

Rolling-moment characteristics.— As shown in figure 5, the rolling effectiveness of the blunt aileron was about 10 percent greater than that of the basic aileron. The values of $\partial C_l / \partial \delta$ were 0.00038 for the blunt aileron and 0.00034 for the basic aileron. In order to provide a comparison with the results of reference 3, tests were made with the wing alone as well as with the wing in the presence of the half-fuselage. Within the accuracy of the data, the fuselage had no effect on the aileron rolling effectiveness.

Aerodynamic characteristics.— The lift, drag, and pitching-moment characteristics of the wing (fig. 6) with either the blunt or basic aileron were the same within the accuracy of the data. The lift-curve

slope $dC_L/d\alpha$ of 0.037 would be increased to 0.044 if based on exposed wing area and the theoretical lift-curve slope considering fuselage upwash was 0.047. This theoretical value was in better agreement with experiment than for the case of fuselage off where the theoretical $dC_L/d\alpha$ was 0.045 as compared with the experimental value of 0.040 (reference 3). The better agreement with theory of the wing in the presence of a fuselage probably was a result of smaller boundary-layer effects at the wing-fuselage juncture than at the wing root when no fuselage was present.

CONCLUSIONS

From tests of basic and blunt ailerons on a 42.7° sweptback wing in the Langley 9- by 12-inch supersonic blowdown tunnel at a Mach number of 1.9, the following conclusions may be drawn:

(1) The rolling-moment coefficients of both ailerons varied approximately linearly with aileron deflection, and the blunt aileron was about 10 percent more effective than the basic aileron.

(2) Hinge moments for both ailerons varied approximately linearly with both angle of attack and aileron deflection and were about 40 percent higher for the blunt aileron than for the basic aileron.

(3) Theoretically calculated hinge moments were in good agreement with experimental results.

(4) There was no measurable difference in drag for the two wing-aileron combinations.

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APPENDIX

METHOD OF CALCULATING HINGE MOMENTS

Flat-plate hinge moments for a wing-aileron combination having the same plan form as the wing tested were calculated by taking into account the conical-flow fields from the wing tip and wing-fuselage juncture as the angle of attack changed and the conical fields at the root and tip of the aileron as the aileron was deflected.

In calculating hinge moments due to wing angle of attack the aileron was assumed to be at zero deflection. The pressure distributions over the portions of the aileron operating within the Mach cones emanating from the wing tip and wing-fuselage juncture were determined from equations given in reference 7. The hinge moments from these portions of the aileron were determined by graphical integration of the pressure. These were then added to the hinge moment of the part of the aileron operating in two-dimensional flow to get the total flat-plate hinge moment of the aileron.

The wing was assumed to be at zero angle of attack for the calculations of hinge moments due to aileron deflection. The pressure distributions over the parts of the aileron operating in the conical-flow fields resulting from aileron deflection were determined from equations given in reference 8. The hinge moments from those parts of the aileron were determined by graphical integration of the pressure. Hinge moments of these conical-flow regions and the regions operating in two-dimensional flow were then added to obtain the total flat-plate hinge moment of the aileron.

The flat-plate hinge moments obtained by the preceding methods were corrected for thickness. This was done by assuming that the ratio of thickness effects on aileron hinge moments were the same for the conical-flow regions as for the two-dimensional-flow regions; that is,

$$\frac{\partial C_h}{\partial \alpha} = \frac{\left(\frac{\partial C_h}{\partial \alpha}\right)_2}{\left(\frac{\partial C_h}{\partial \alpha}\right)_1} \left(\frac{\partial C_h}{\partial \alpha}\right)_3$$

$$\frac{\partial C_h}{\partial \delta} = \frac{\left(\frac{\partial C_h}{\partial \delta}\right)_2}{\left(\frac{\partial C_h}{\partial \delta}\right)_1} \left(\frac{\partial C_h}{\partial \delta}\right)_3$$

where the subscripts denote:

- (1) Two-dimensional flat plate
- (2) Three-dimensional flat plate
- (3) Two-dimensional with thickness

Two-dimensional hinge moments considering thickness were calculated by using the "Busemann second-order approximation theory" discussed in reference 9. This theory is limited to conditions where the shock wave at the leading edge of the airfoil is attached to the airfoil. The wing for which the present calculations were made, however, had a half leading-edge angle in a plane normal to the leading edge which was larger than the angle at which a shock wave detaches for the Mach number component normal to the leading edge. It was assumed that the existing detached shock did not invalidate the theory used and consequently did not affect the calculated hinge moments.

In calculating hinge moments due to angle of attack, the Mach number component and aileron section contour in a plane normal to the wing leading edge were used. The Mach number component and aileron section contour in a plane normal to the aileron hinge line were used in calculating hinge moments due to aileron deflection.

Calculations, made by using the method previously discussed, give hinge moments which are in good agreement with experimental values. (See table II.) Table III gives a breakdown of calculated hinge moments.

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TABLE I

ORDINATES FOR AIRFOIL SECTION OF 42.7° SWEEPBACK TAPERED WING

[Stations and ordinates given in percent airfoil chord in free-stream direction; section symmetrical about chord line.]

Station	Ordinate
0	0
5	.712
10	1.357
15	1.935
20	2.444
25	2.884
30	3.253
35	3.549
40	3.772
45	3.919
50	3.989
55	3.981
60	3.892
65	3.720
70	3.463
75	3.120
80	2.686
85	2.161
90	1.540
95	.821
100	0

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TABLE II

EXPERIMENTAL AND CALCULATED HINGE-MOMENT
CHARACTERISTICS FOR BASIC AND BLUNT ALLERONS

	Basic	Blunt
$\left(\frac{\partial C_h}{\partial \alpha}\right)_{\text{exp.}}$	-0.010	-0.014
$\left(\frac{\partial C_h}{\partial \alpha}\right)_{\text{cal.}}$	-.010	-.016
$\left(\frac{\partial C_h}{\partial \delta}\right)_{\text{exp.}}$	-.010	-.014
$\left(\frac{\partial C_h}{\partial \delta}\right)_{\text{cal.}}$	-.009	-.013

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TABLE III

RESOLUTION OF CALCULATED HINGE-MOMENT CHARACTERISTICS

Condition	Basic aileron		Blunt aileron	
	$\partial C_h / \partial \alpha$	$\partial C_h / \partial \delta$	$\partial C_h / \partial \alpha$	$\partial C_h / \partial \delta$
Two-dimensional flat plate	-0.0263	-0.0197	-0.0263	-0.0197
Three-dimensional flat plate	-.0195	-.0157	-.0195	-.0157
Two-dimensional with thickness	-.0135	-.0116	-.0212	-.0161
Three-dimensional with thickness	-.0100	-.0092	-.0157	-.0128

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Figure 1.- Photograph of 42.7° sweptback wing and fuselage.

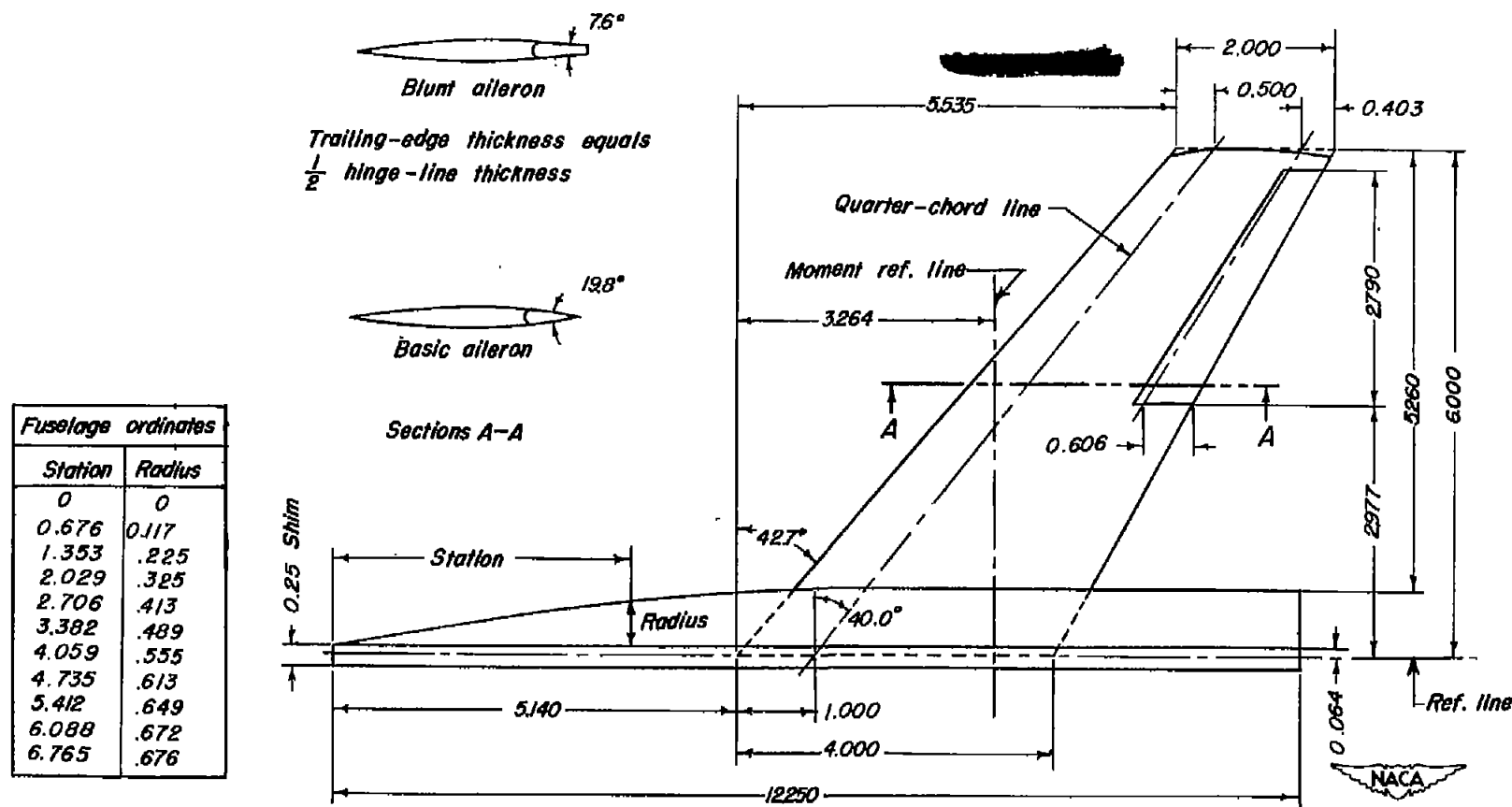


Figure 2.— Details of 42.7° sweptback wing, ailerons and fuselage. Area aileron 1.430; area wing 17.943; M.A.C. 3.101. All dimensions in inches.

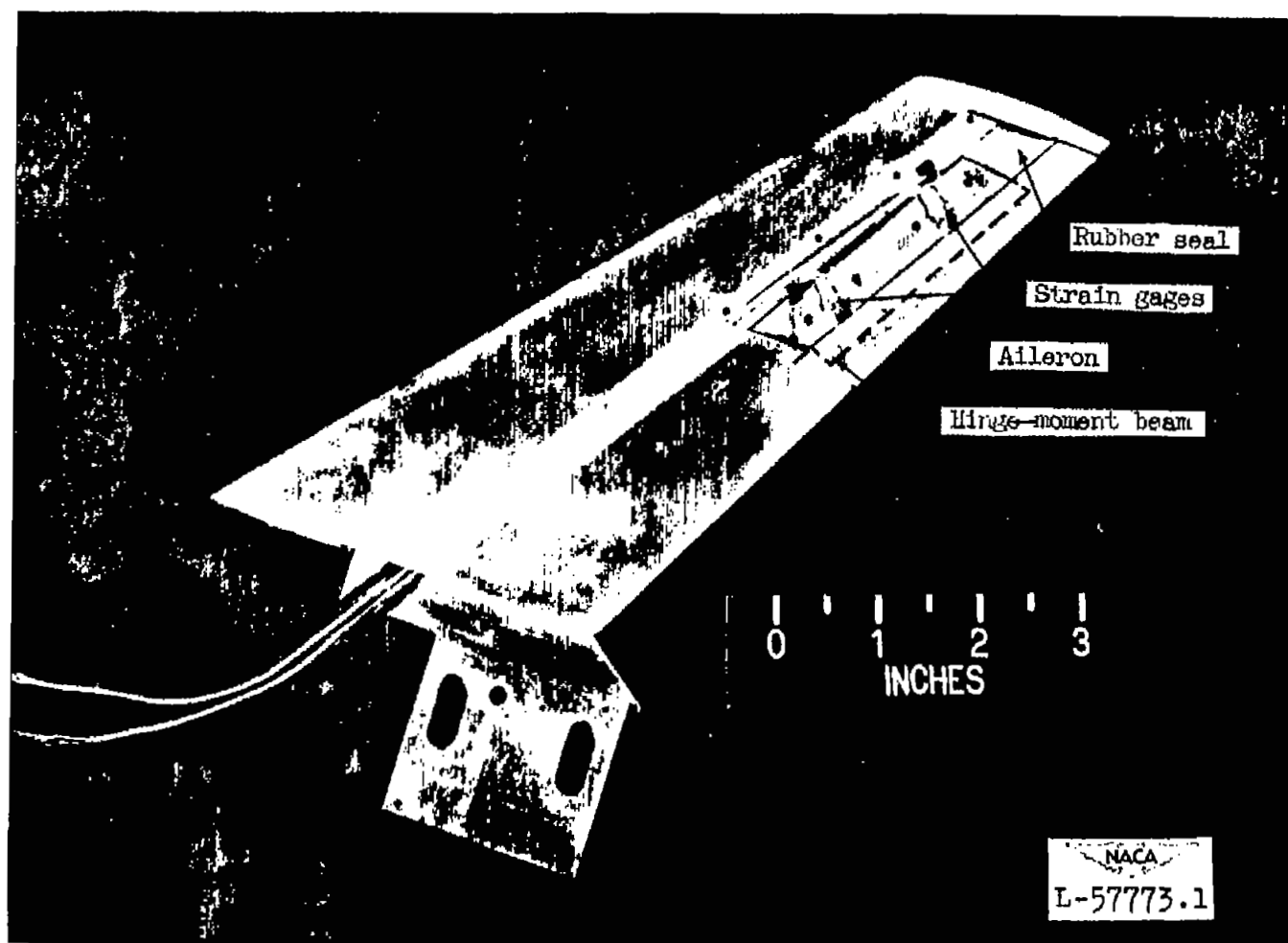
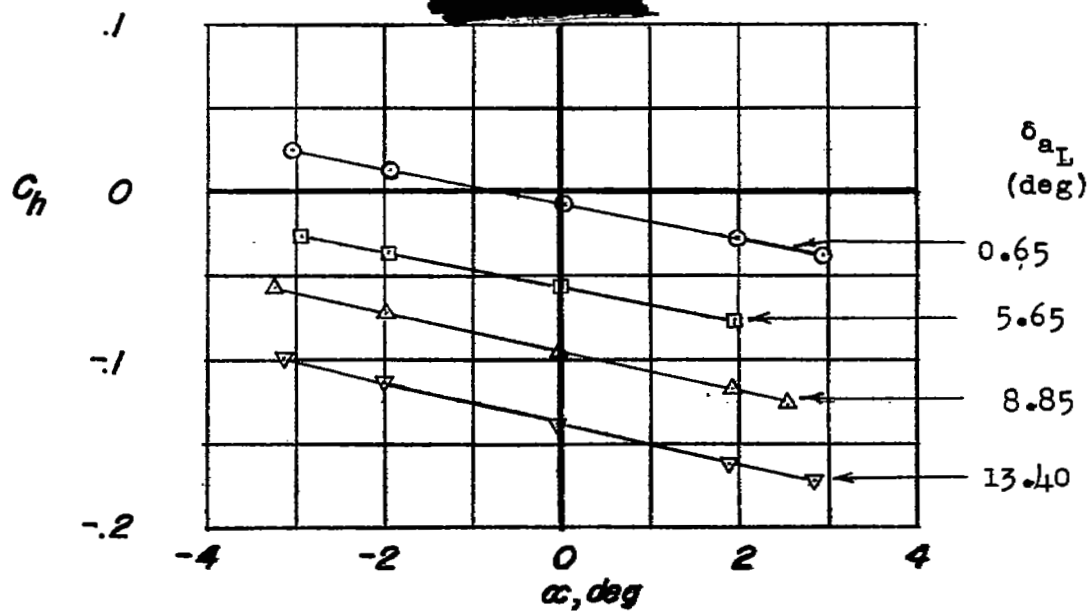
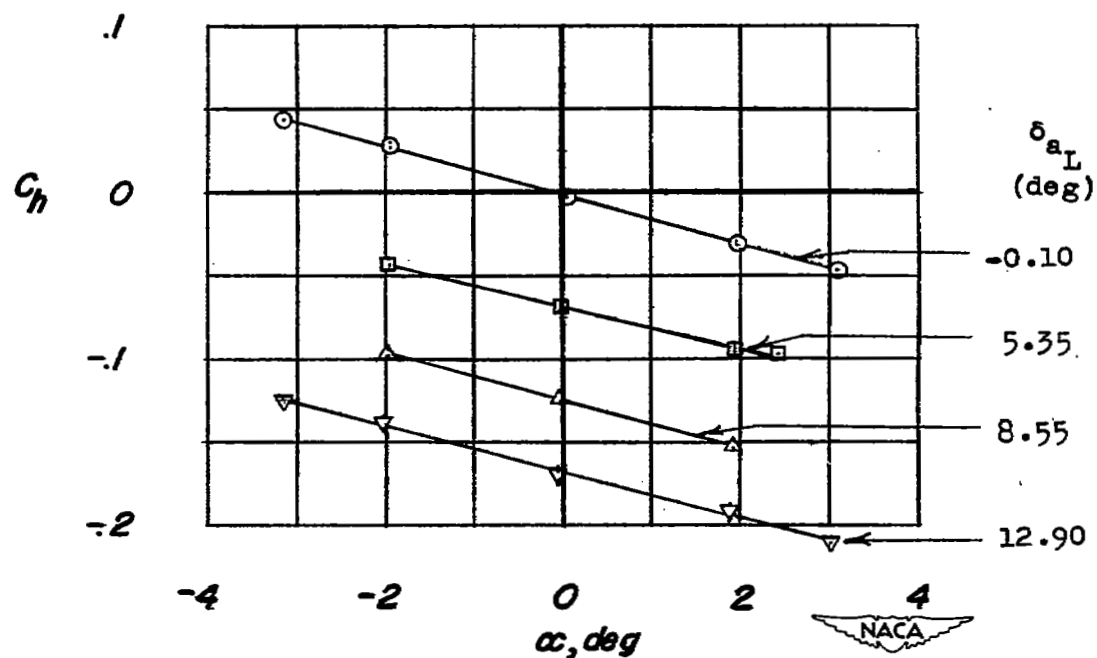


Figure 3.- Details of hinge-moment-beam installation on a 42.7° sweptback wing. Cover plate removed.



(a) Basic aileron.



(b) Blunt aileron.

Figure 4.—Hinge-moment characteristics of basic and blunt ailerons on a 42.7° sweptback wing; fuselage on; $M = 1.9$; $R = 2.2 \times 10^6$.

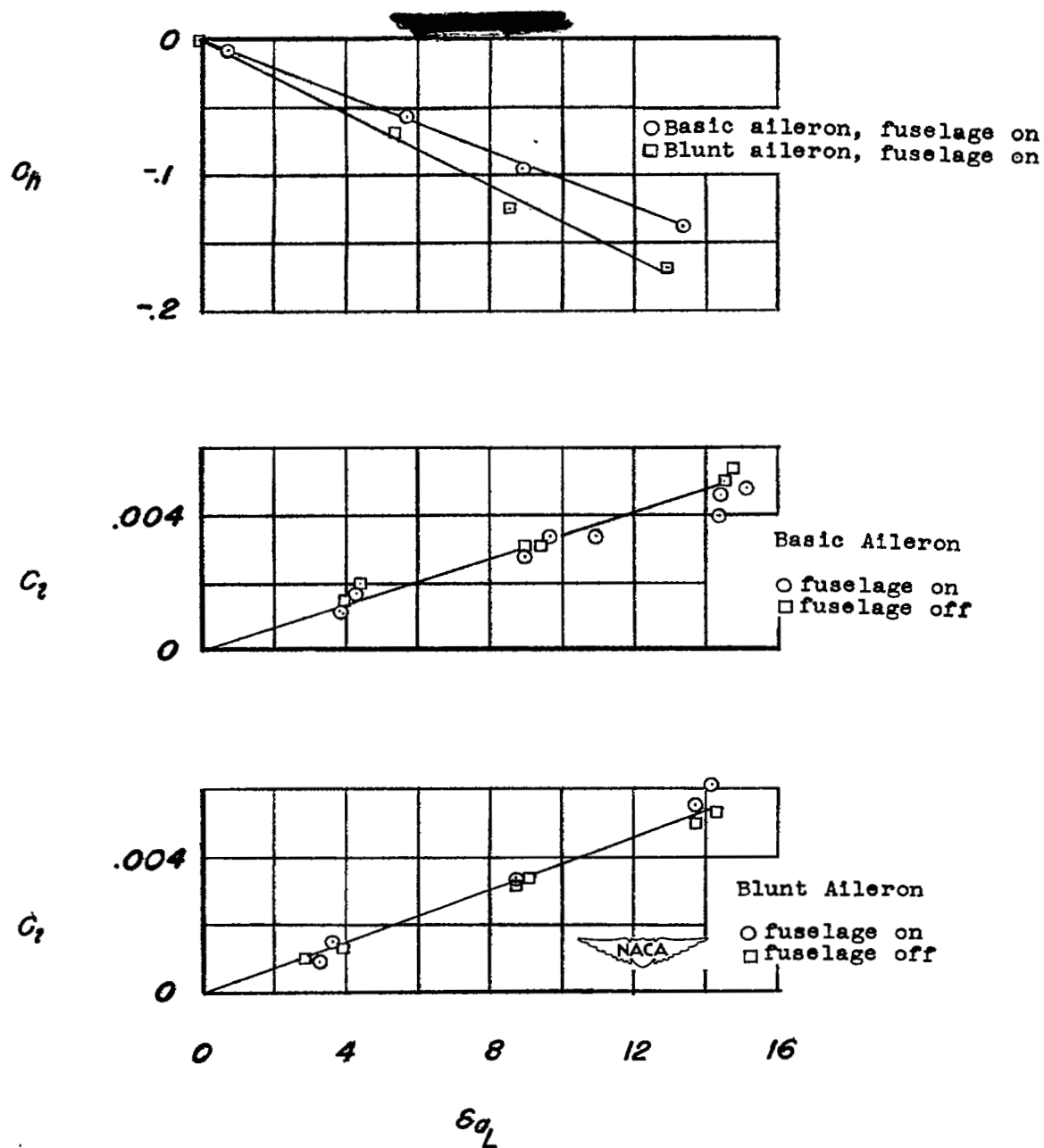


Figure 5.— Characteristics of basic and blunt ailerons on a 42.7° swept-back wing; $\alpha = 0^\circ$; $M = 1.9$; $R = 2.2 \times 10^6$.

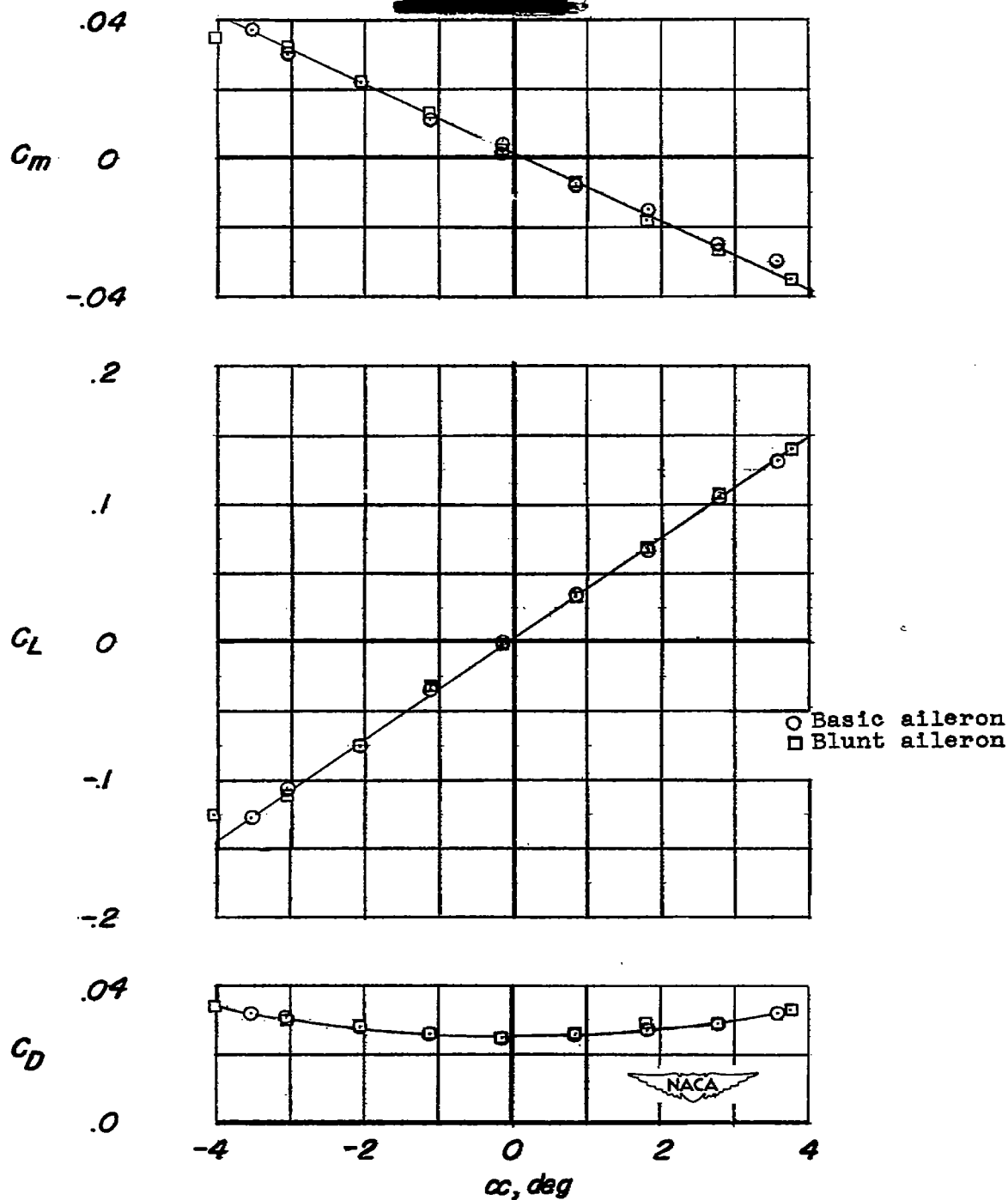


Figure 6.- Aerodynamic characteristics of a 42.7° sweptback wing with either blunt or basic aileron; fuselage on; $\delta_{aL} = 0^\circ$; $M = 1.9$; $R = 2.2 \times 10^6$.

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